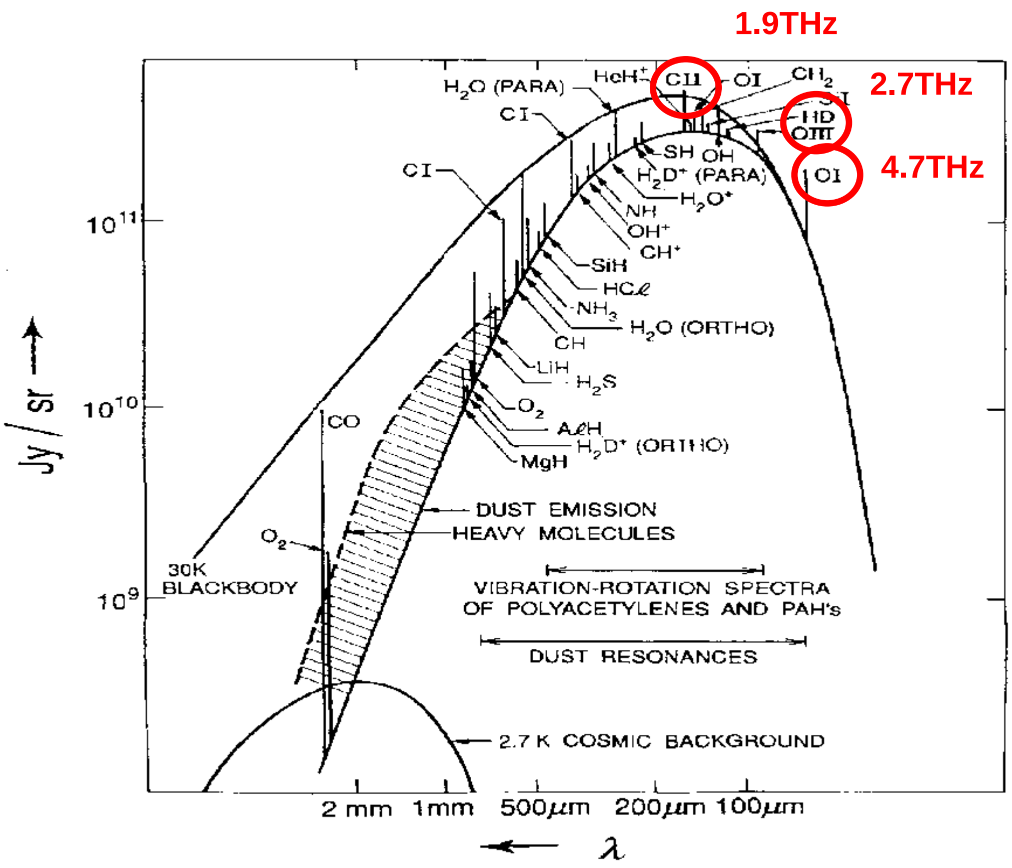
MgB_2 Hot Electron Bolometers for Array Receivers

Daniel Cunnane[*1], Narendra Acharya[2],
Wenura K. Withanage[2], Xiaoxing Xi[2], Jonathan Kawamura[1], and Boris S. Karasik[1]

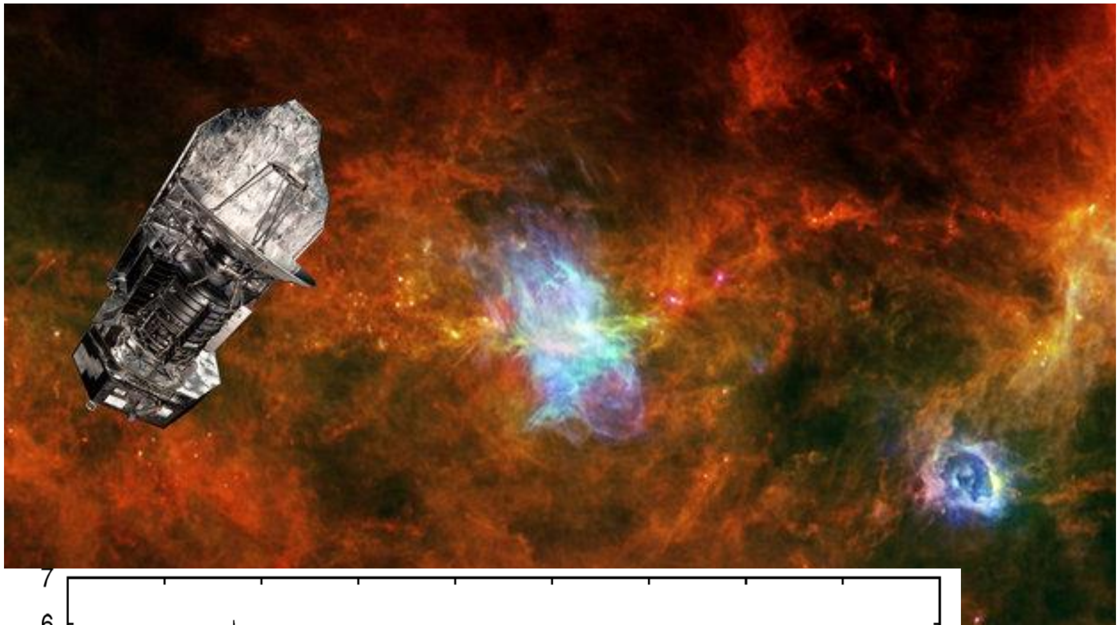
[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA
[2]Temple University, Philadelphia, PA 19122, USA
[*]Contact: daniel.p.cunnane@jpl.nasa.gov

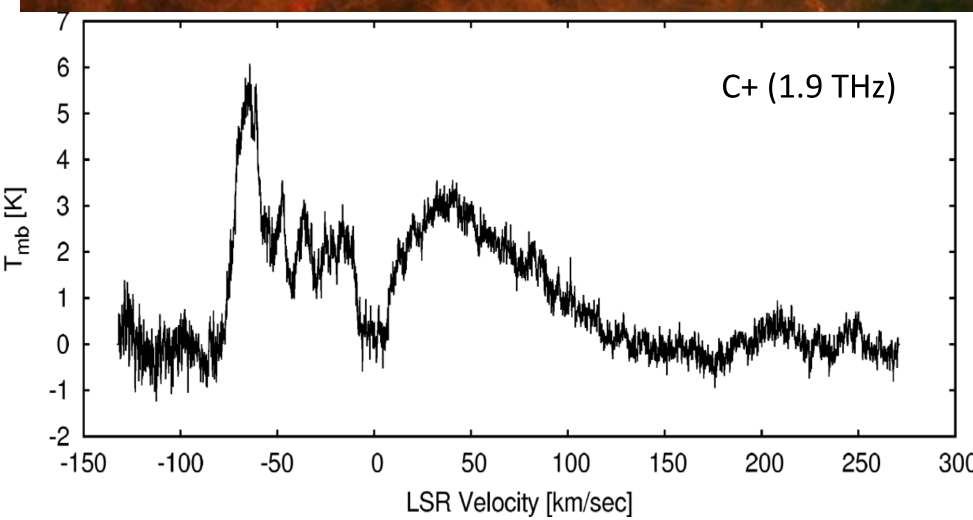
Science Targets of Interest:



- HEB operation at elevated temperature which can be achieved by 20-25 K mechanical cryocoolers (in space)
- Achieving higher than in the state of the art NbN mixers IF bandwidth in order to enable spectroscopic measurements of highly Doppler broadened THz lines (up to 8-10 GHz is required).

Larger Bandwidth Needed at Higher Frequencies



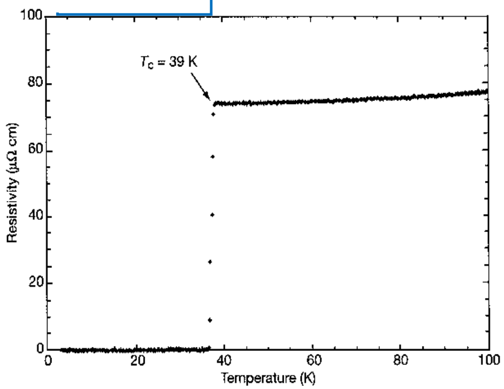


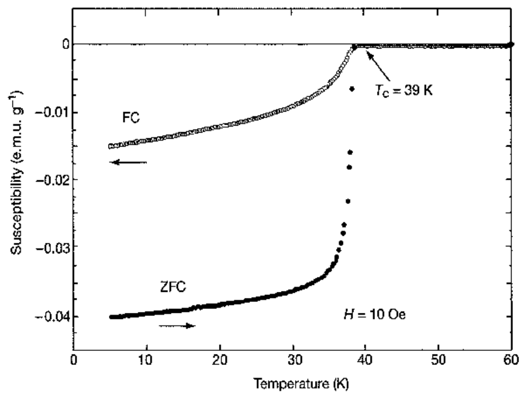
~ 3 GHz

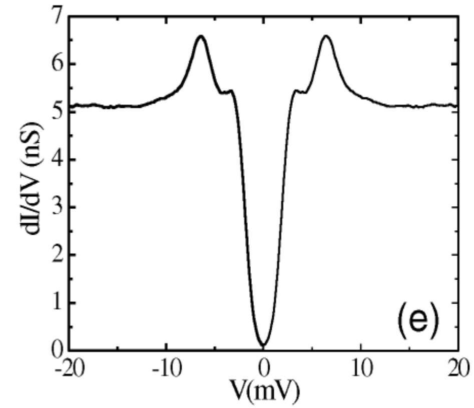
- Using Herschel HIFI, a scan of GC at 1.9 THz had features spanning 450 km/sec.
- $\Delta f = \frac{\Delta v}{c} f_0$
- A similar scan for the 4.7 THz OI line would require over 7 GHz to obtain the same velocity span.

Superconductivity in MgB_2

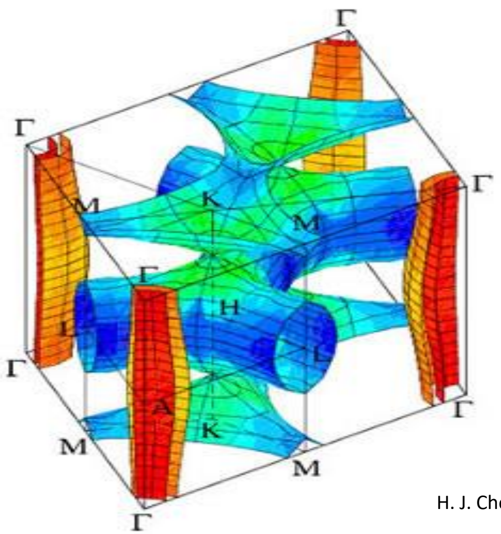
M. Iavarone et al., Phys. Rev. Lett. **89,** 187002 (2002).

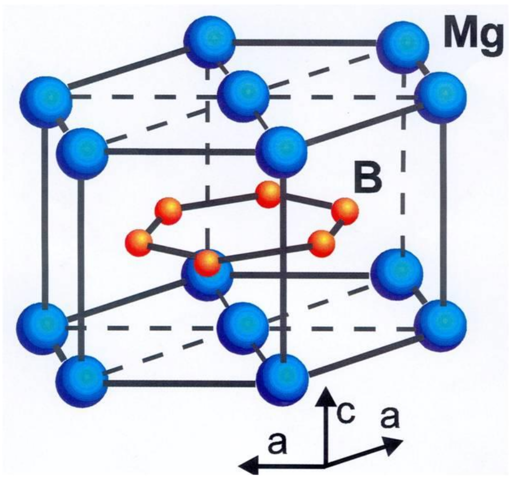






J. Nagamatsu et al., Nature **410**, 63 (2001).

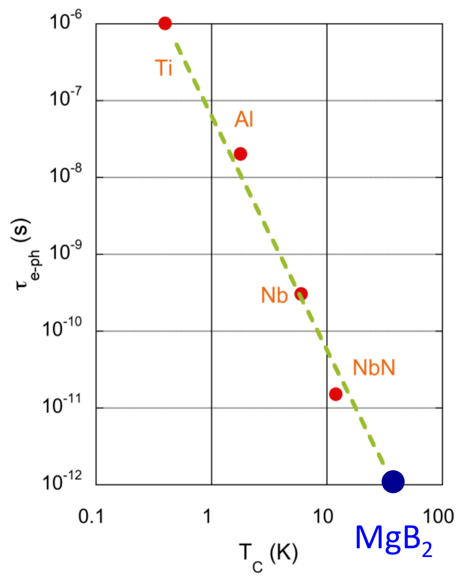


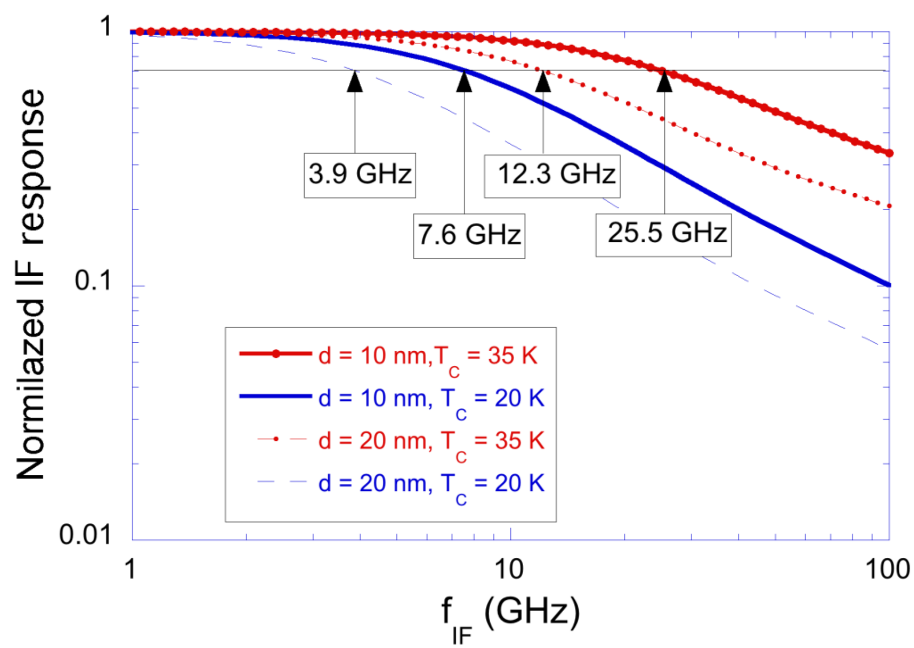


H. J. Choi et al., Nature **418**, 758 (2002).

MgB_2 Potential for HEB Applications

Material	MgB_2	NbN	MgO	SiC	Si
ρ (g cm^{-3})	2.7	8.5	3.6	3.2	2.3
v_s (km/s)	7.8	2.5	6.6	7.5	6
Z_a (10^6 kg m^{-2} s^{-1})	21	21	24	24	14





- Well acoustically matched to substrates of interest.
- 2-Temperature model predictions yield small effective τ which will result in a large intermediate frequency (IF) bandwidth.
- Additional benefit of variable resistivity for impedance matching.

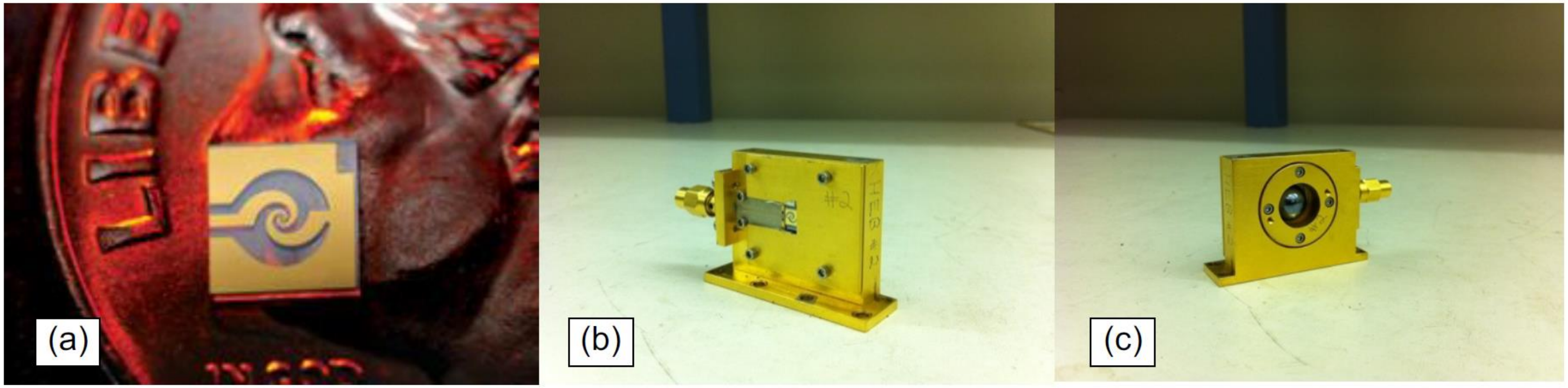
Comparison to SOA at 4.7 THz

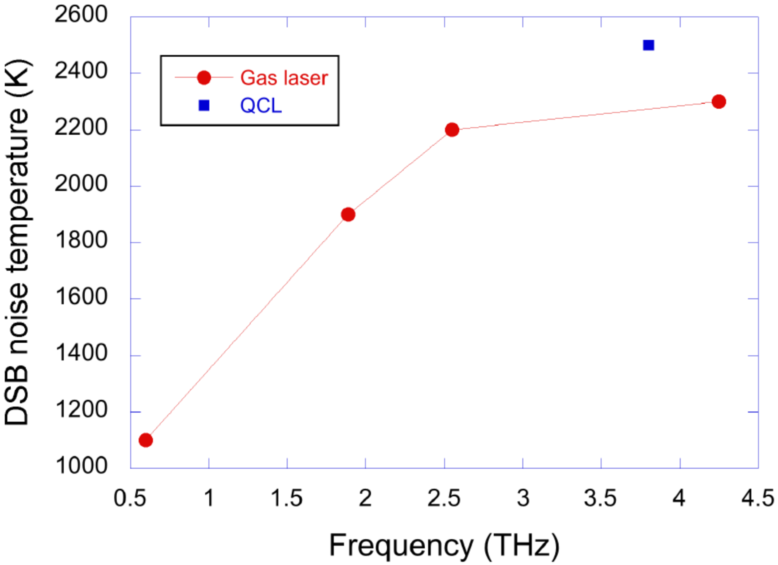
Parameter	SOA NbN HEB mixer		Current MgB_2 QO HEB mixer
	WG	QO	
DSB noise temp. (K)	1100	815	2300 @4.3 THz
IF noise BW (GHz)	≈ 3	≈ 3	≈ 7
Operating temp. (K)	4.6	4.2	15
Array size	1 × 1	1 × 1	1 × 1
LO type	QCL	QCL	far-IR laser

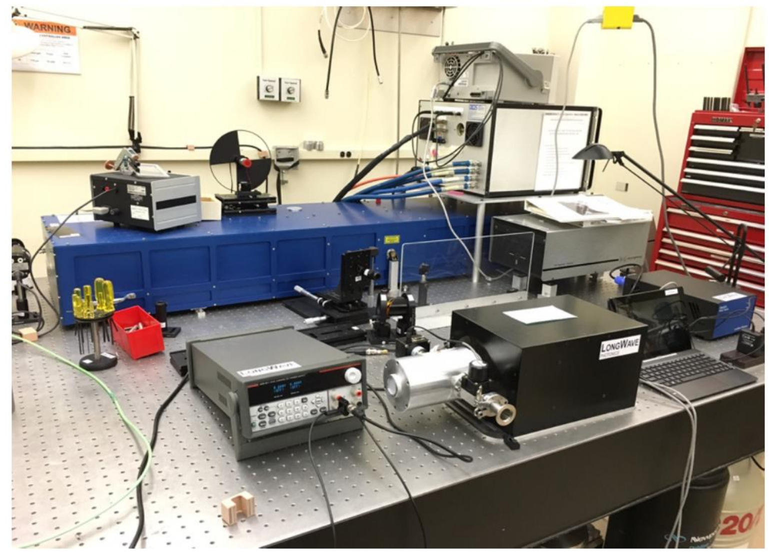
WG) D. Büchel *et al.*, "4.7-THz Superconducting Hot Electron Bolometer Waveguide Mixer," *IEEE Trans. THz Sci. Technol.*, vol. 5, no. 2, pp. 207-214, 2015.

QO) J. L. Kloosterman *et al.*, "Hot electron bolometer heterodyne receiver with a 4.7-THz quantum cascade laser as a local oscillator," *Appl. Phys. Lett.* , vol. 102, p. 011123, 2013.

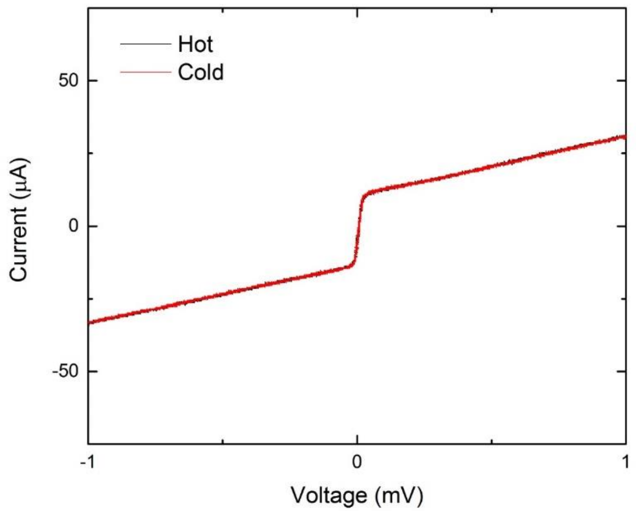
MgB_2 Quasi-Optical Mixers

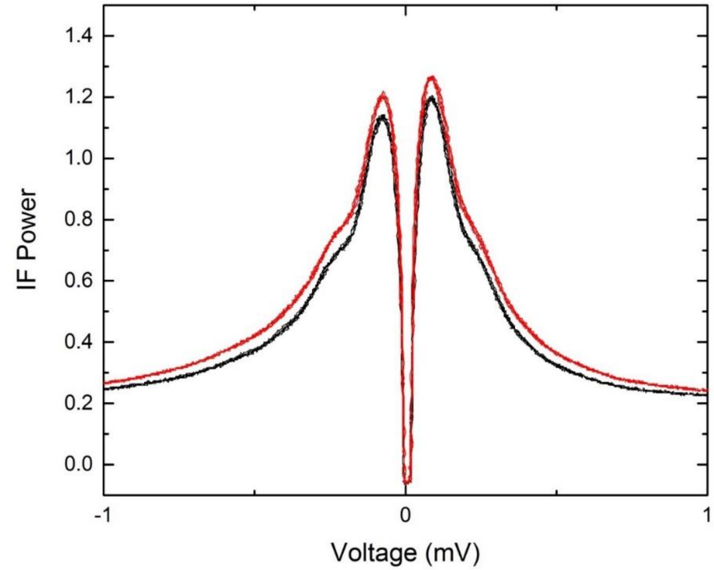


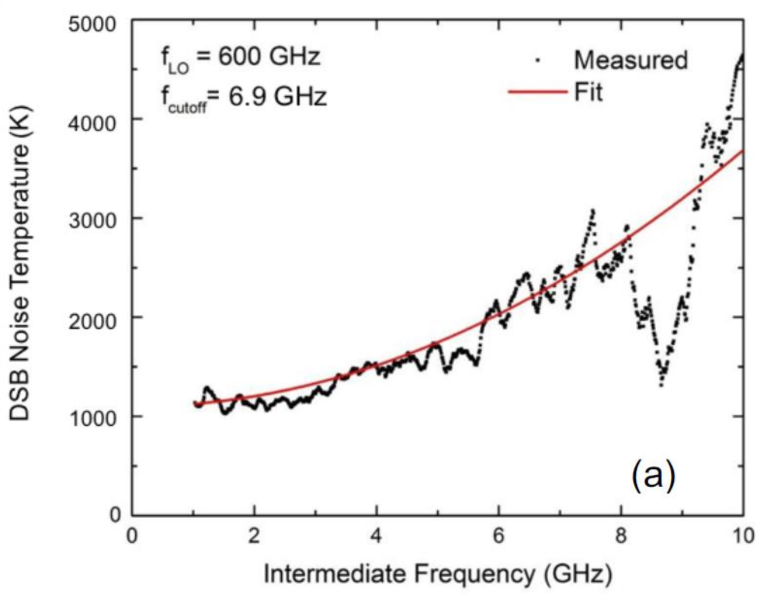


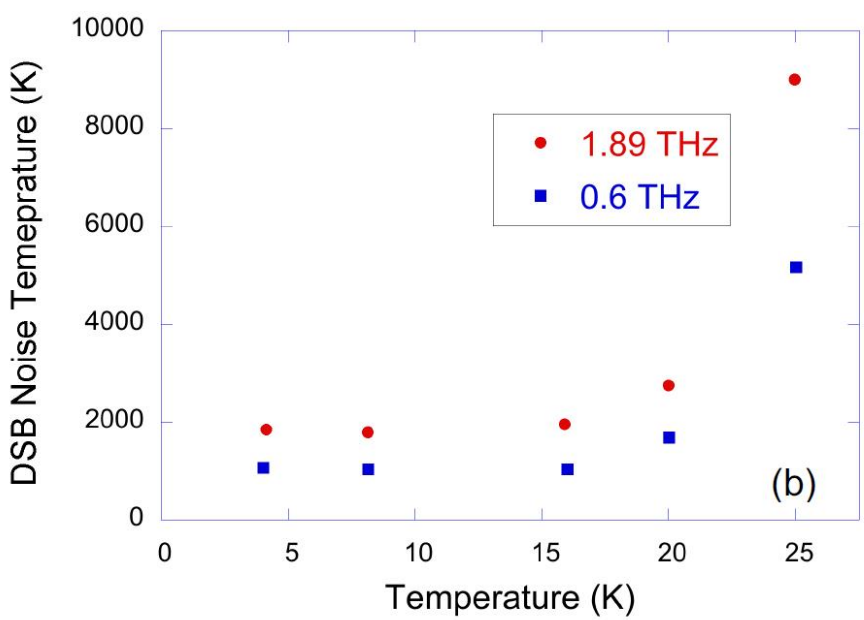


MgB_2 Quasi-Optical Mixers



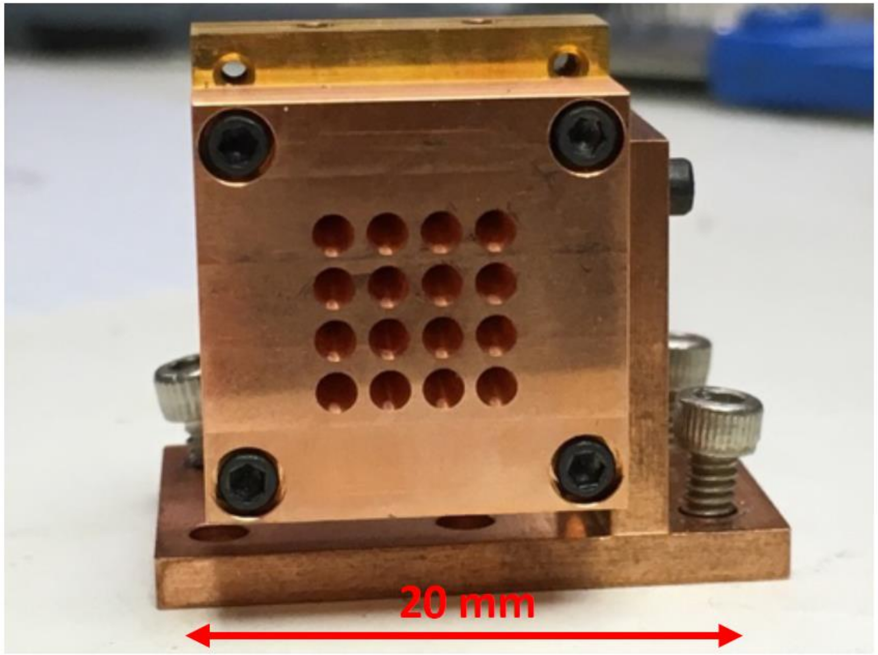


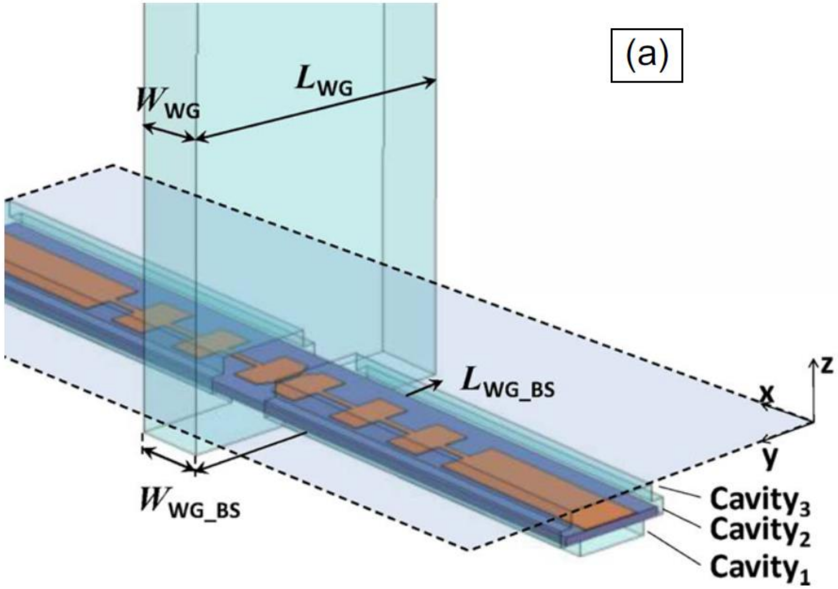


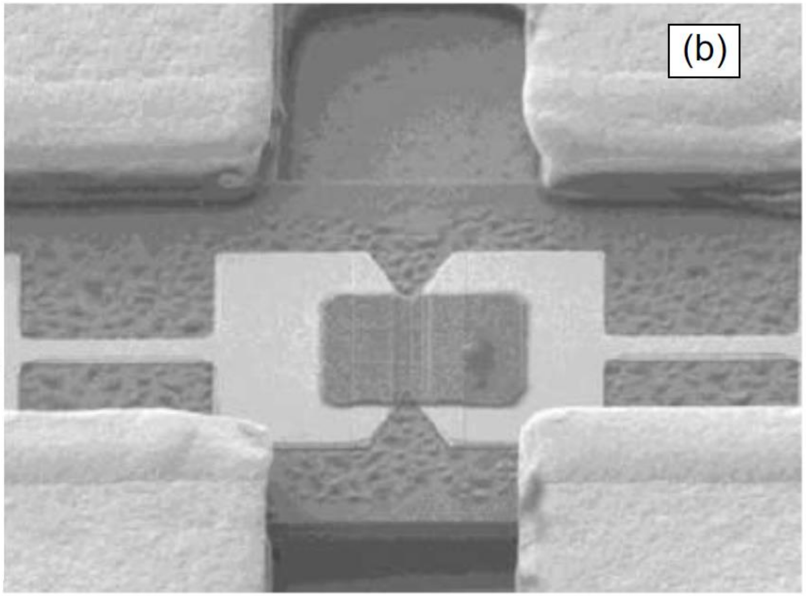


Goal: Waveguide Mixers

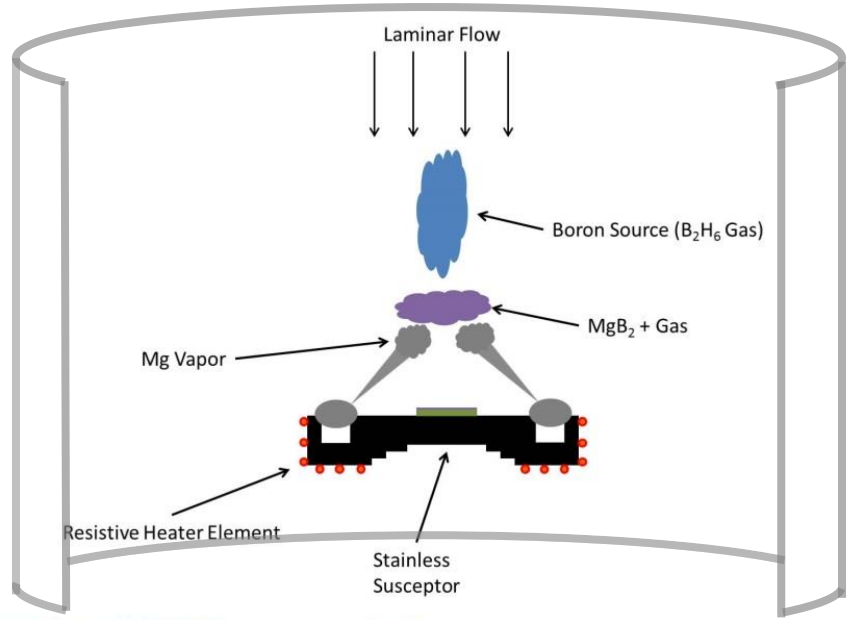
- Need to develop devices on SOI substrates with 3-6 µm device layer thickness.
- Need to show that backside alignment and etch of the handle wafer do not effect device performance.

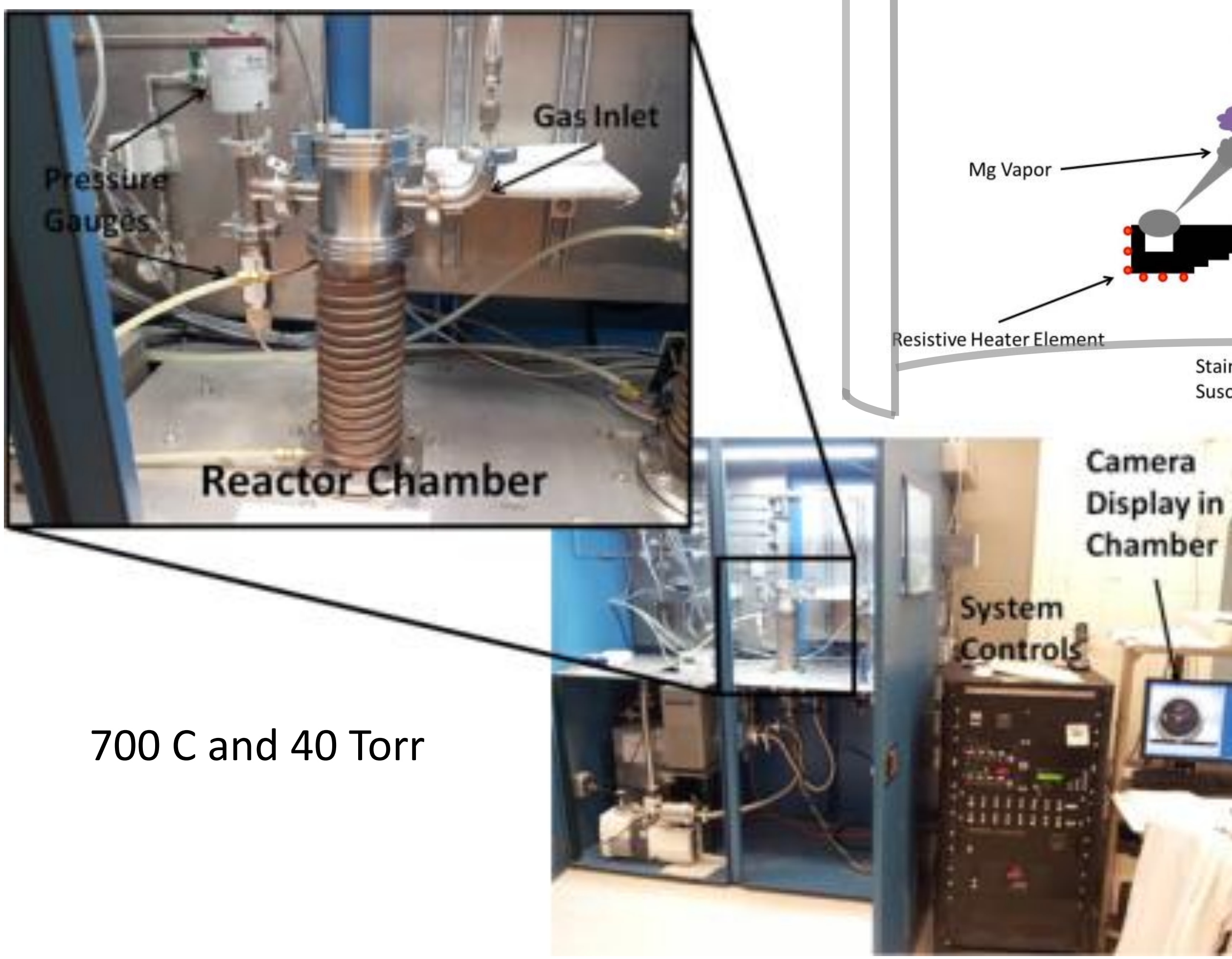






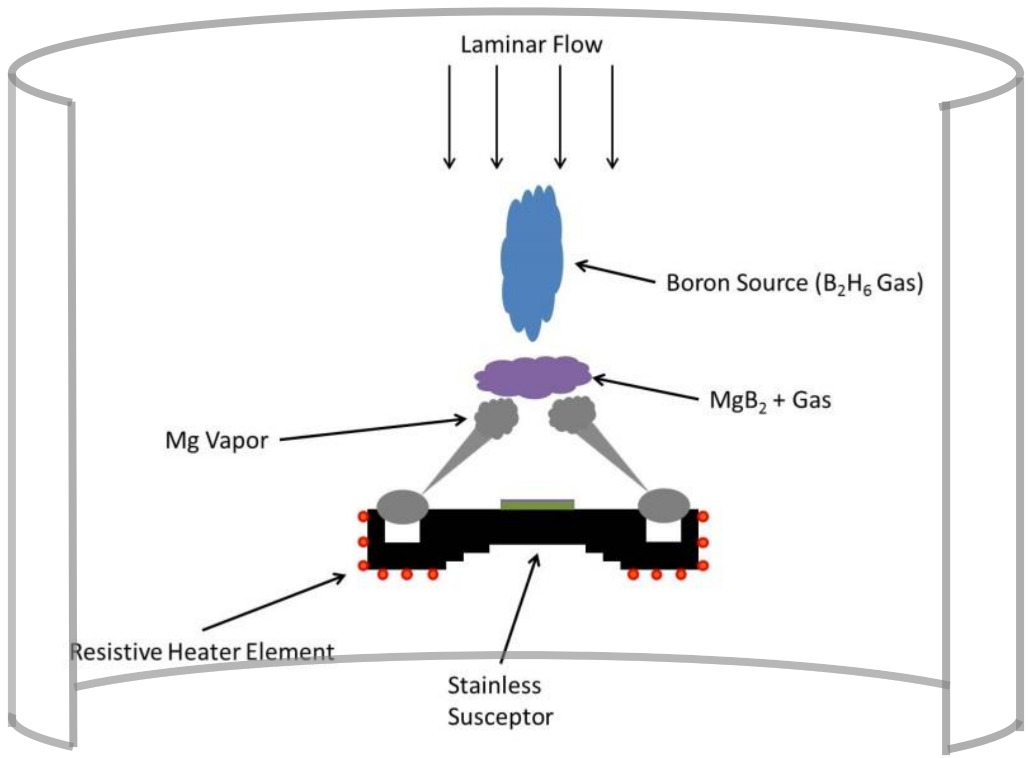
HPCVD Grown MgB_2 Thin Films





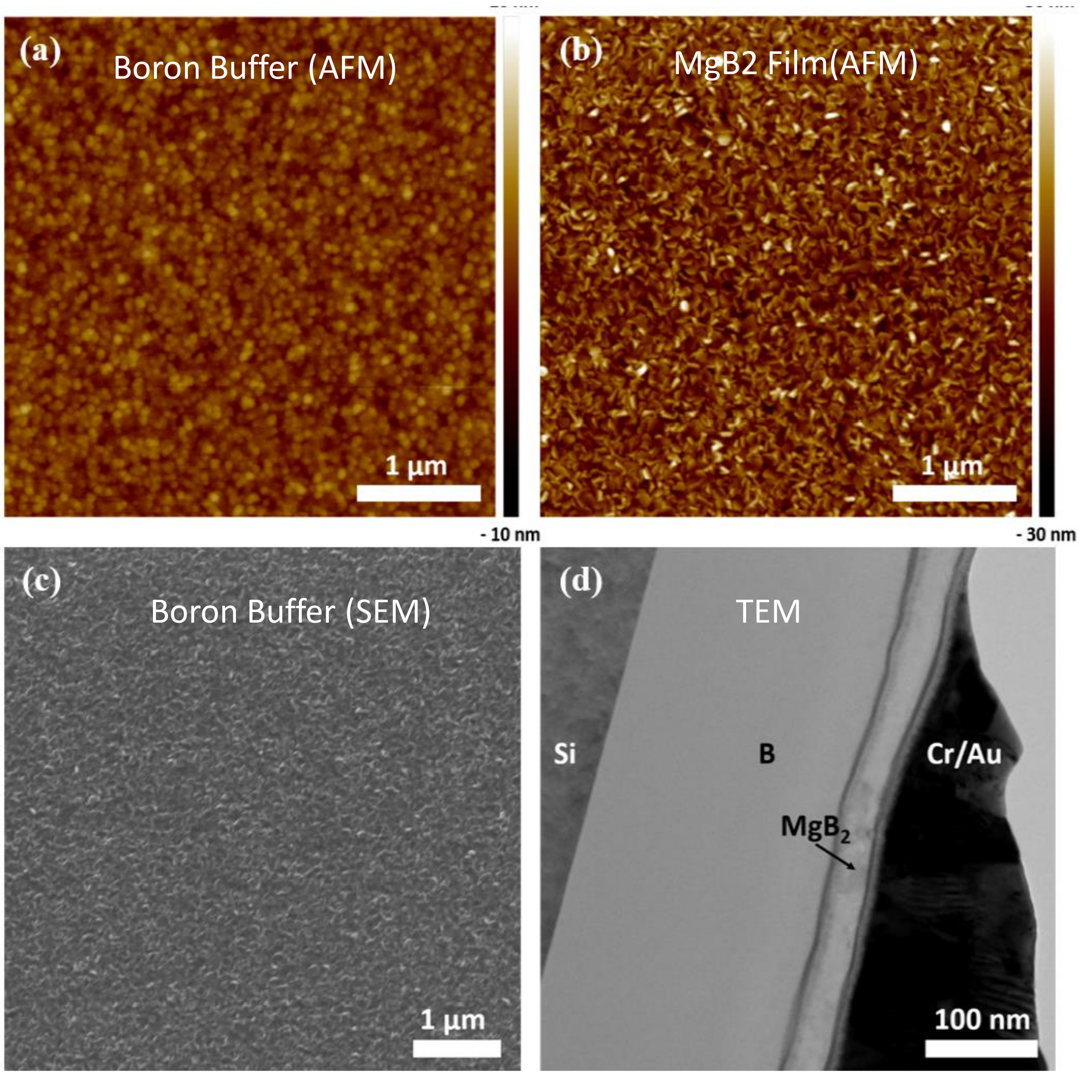
700 C and 40 Torr

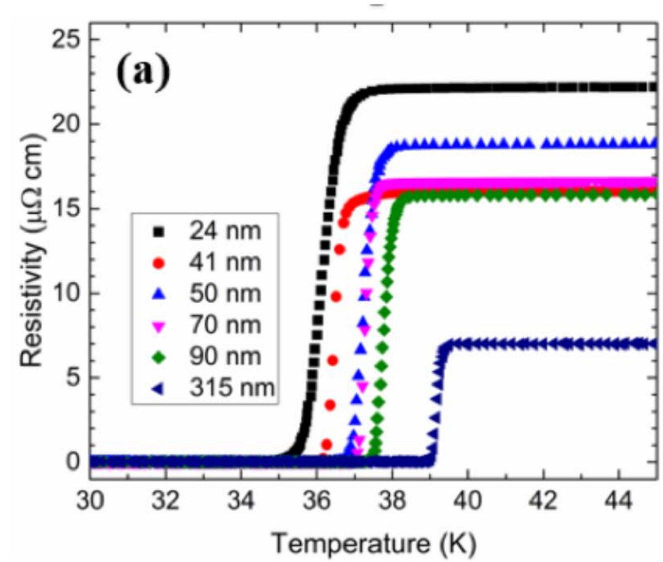
CVD Boron Thin Films as a Buffer



- Obstacle: Reaction between Si and Mg around 450 C
- Solution: Intermediate Buffer layer
  - MgO was the first choice, but smooth MgO films cracked during higher temperature MgB_2 deposition
  - Boron films first used to grow MgB2 on Cu (same issue) for SRF applications.

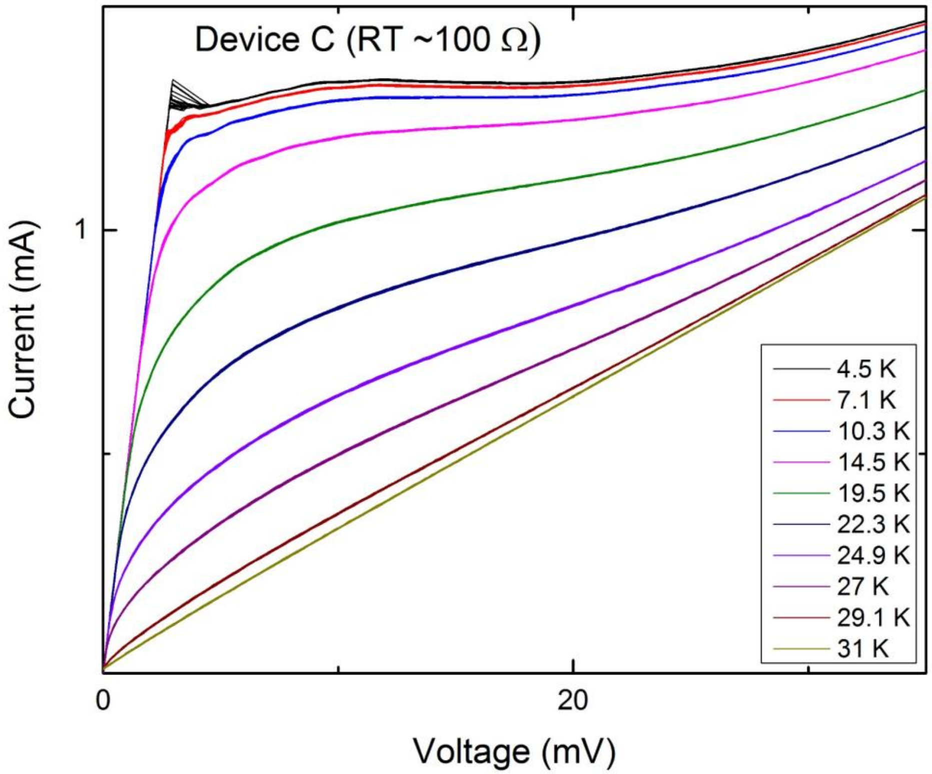
Films on Si Substrate





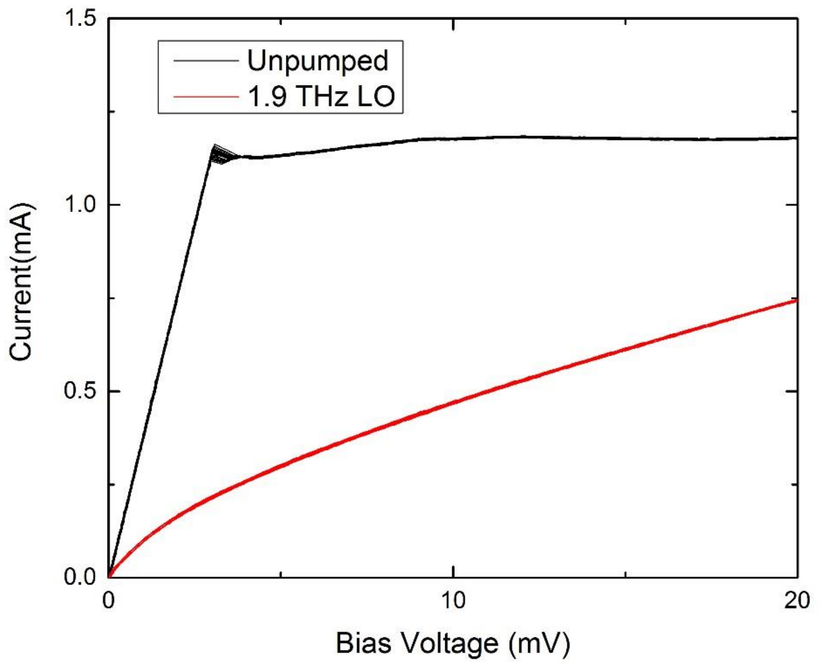
- Poor Roughness of Boron films lead to poor roughness of MgB2 films.
- Very clean interfaces implies room for improvement.

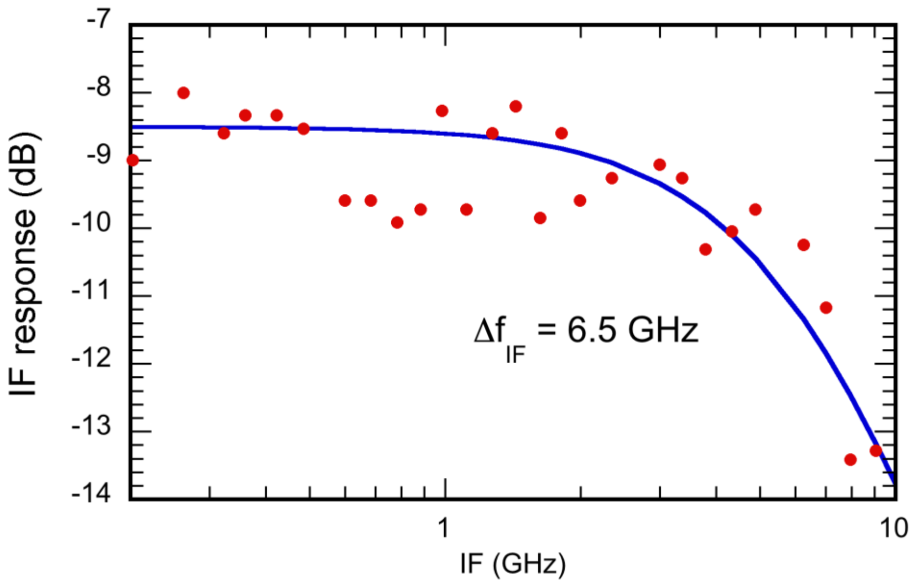
HEB Devices on Si Substrate (DC characterization)



- 20 nm Film
- T_c corresponds with what was seen for Films
- ΔT_c is ~4 K, leading to poor sensitivity (expected problem is from film non-uniformity)
- J_c is a factor of 2 lower than bare films (6 MA/cm^2 compared to >10MA/cm^2 in films)

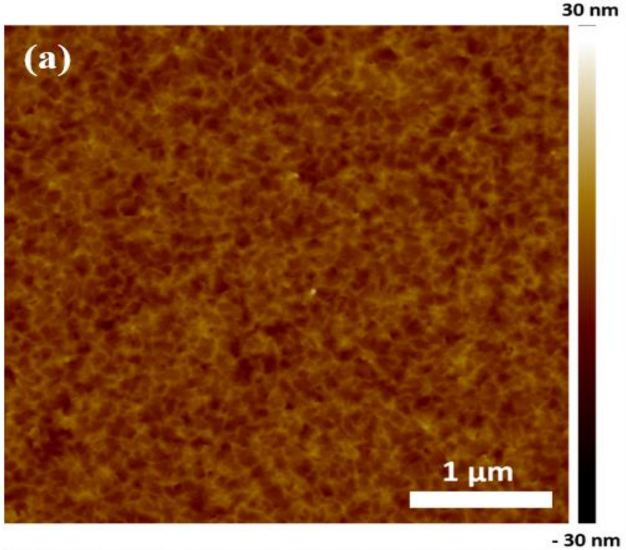
HEB Devices on Si Substrate (RF characterization)



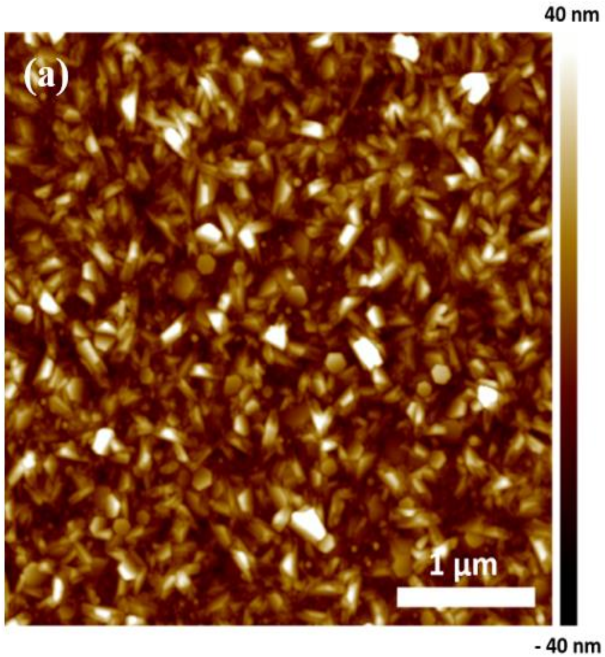


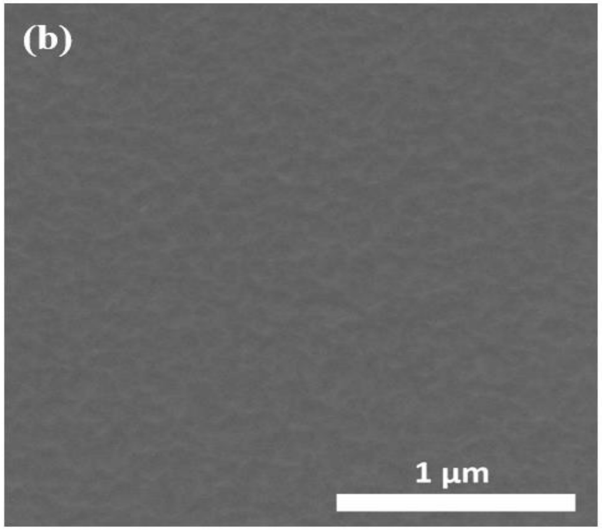
- THz pumping of devices is easier than previous devices.
  - Device Tc is somewhat lower
  - Impedance matching is improved (low temp device resistance approx. 30 ohms)
- Gain bandwidth measurement done with microwave frequencies.
  - Bandwidth identical to device on SiC substrate with similer film thickness (6.5 GHz).

Optimization of Films and Growth on SOI

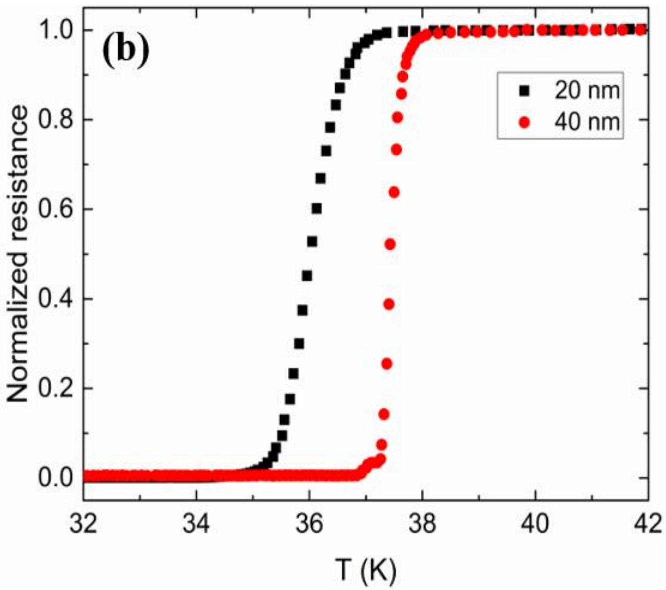


Ion milling at a very shallow angle can improve the roughness significantly (factor of 2-5). This was used to achieve ~3 nm films with Tc > 30 K.





Films can be grown on SOI substrates without any further degradation of the SC properties.



Summary:

- Consistently see an IF bandwidth around 7 GHz for a 15 nm film
  - Bandwidth confirmed even when moving to the polycrystalline films on Si Substrates.
- Noise temperature of MgB_2 HEBs about 2x larger than SOA NbN devices
  - Still significant room for improvement, particularly with impedance matching
  - NT of MgB_2 HEBs on Si Substrate needs further work, particularly, more uniform films to achieve smaller ΔT_c.
  - Polycrystalline films on Si have larger sheet resistance which will make impedance matching easier.
- MgB_2 films have been grown on SOI substrates and efforts are under way to fabricate some WG coupled HEBs for frequencies from 1.9 THz to 4.7 THz.